

DIGITAL ELECTRONIC ENGINE CONTROL HISTORY

Terrill W. Putnam
NASA Ames Research Center
Dryden Flight Research Facility
Edwards, California

SUMMARY

Full authority digital electronic engine controls (DEECs) have been studied, developed, and ground tested for many years because of projected benefits in operability, improved performance, reduced maintenance, improved reliability, and lower life cycle costs. All of these benefits cannot be truly assessed until DEECs are produced in quantity and operated over a significant length of time. However, the issues of operability and improved performance can be assessed in a flight test program.

As part of NASA's ongoing commitment to extend and improve propulsion system technology, the NASA Dryden Flight Research Facility entered into an agreement with the U.S. Air Force (USAF) Deputy for Propulsion and the Government Products Division of Pratt and Whitney Aircraft to demonstrate and evaluate the DEEC on an F100 engine in an F-15 aircraft.

The events leading up to that flight test program are chronicled and important management and technical results are identified.

HISTORY

The DEEC program began in 1973 with configuration studies conducted by Pratt and Whitney. In 1978, NASA Lewis Research Center (LeRC) began its participation in the program by testing a breadboard version of a DEEC on engine P072 in an altitude facility. In 1979, the USAF requested that Dryden demonstrate and evaluate the DEEC by flying a DEEC-equipped F100 engine in one of the USAF F-15s loaned to NASA. The NASA flight test program began in 1981; this history covers the events up until that time.

It should also be observed that Pratt and Whitney developed the DEEC on independent research and development (IR&D) funds. During the mid-1970s, two other digital engine programs were also improving and adding to the digital engine control data base. They were the full authority digital engine control (FADEC) program sponsored by the U.S. Navy (USN) and the integrated propulsion control system (IPCS) program sponsored by the USAF and NASA.

DEEC History

NASA
DFRF83-617a

Event	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
Configuration Studies	▽										
USAF Design Review		▽									
Full-Scale Dev. Proposal			▽								
Breadboard Eng. Test				▽							
F100 Conf. Studies				▽							
F-16 DEEC Proposal						▽					
Group I Hardware Rec						▽					
NASA LeRC P072 Tests						▽					
Group I Engine Test							▽				
USAF Request to NASA							▽				
AEDC Flight Clearance							▽				
Sneak Circuit Analysis							▽				
PS2 Flight Tests							▽				
NASA F-15 Flight Test								▽			
50,000 Hr. Cert Test									▽		
Full-Scale Dev. Award										▽	
USAF F-16 Flight Test											▽

PROGRAM AGREEMENT

One of the keys to the success of the DEEC program was the agreement between NASA and the USAF. The existing USAF/NASA memorandum of agreement (MOA) for the F-15 program was used so that no new formal agreements had to be developed and approved. It was agreed among the program participants that the program would be cooperative and mutually beneficial to each participant.

NASA/USAF DEEC Program Agreement

NASA
DFRF83-618

1979 - USAF - ASD/YZ requests NASA to flight test the DEEC/SA in a mutually beneficial cooperative program

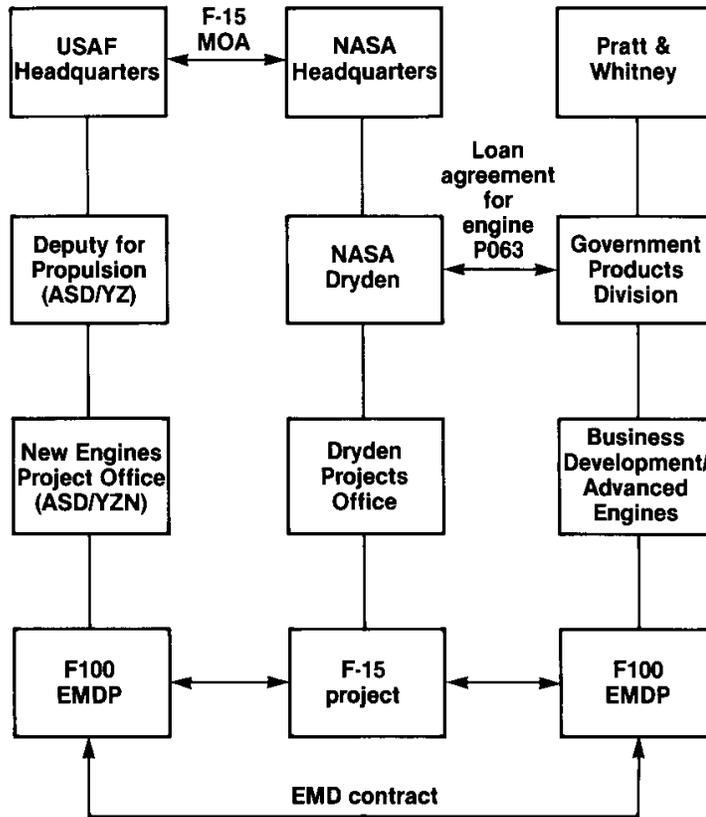
- **Related to NASA Interact Program**
- **USAF initiated Engine Model Derivative Program**
- **Utilized NASA/USAF F-15 MOA**
- **USAF & P&W propose cooperative DEEC/SA demonstration program**

PROGRAM MANAGEMENT

Another key to the success of the DEEC program was the management structure. The program and technical decisions were usually made at the first level of management within the respective organizations. Also shown is the organizational level at which the loan agreement for engine P063 and the F-15 MOA were implemented.

DEEC Program Management

NASA
DFR83-1795



ORGANIZATIONAL RESPONSIBILITIES

The responsibilities for the DEEC program were divided between NASA, USAF, and Pratt and Whitney, as shown. There was practically no overlap and each organization possessed the knowledge, skills, and resources necessary to discharge respective responsibilities.

Organizational Responsibilities

NASA
DFRF83-620

NASA

- Conduct of the Flight Test Program & Reporting of Results
- Provide Altitude Facility Support as available
- Provide Funding for F-15 and Altitude Facility
- Responsible for Flight Safety

USAF

- Provide AEDC Test Support including funding
- Develop and implement USAF Flight Clearance Requirements
- Conduct Program Reviews

P & W

- Conduct S/L Tests and support Altitude & Flight Tests
- Provide DEEC control hardware and software
- Update F100 (2 $\frac{7}{8}$) engine to F100 (3) configuration
- Provide funding for hardware and software development and support

SWIRL AUGMENTOR

The program originally agreed to by NASA, USAF, and Pratt and Whitney was for the demonstration and evaluation of both a DEEC and a swirl augmentor (SA). The objectives of that program are listed. The swirl augmentor was designed to primarily improve the steady state augmentor performance, increase the rumble altitude limit, reduce the idle thrust, and reduce the infrared (IR) signature of the engine.

DEEC/Swirl Augmentor

NASA
DFRF83-621

Objectives

- Improve Safety, Reliability and Maintainability
- Improve ULHC Transient Performance
- Improve Augmentor Steady State Performance
 - Raise Rumble Altitude limit
 - Reduce IR signature
- Reduce Ground Idle Thrust
- Reduce Required Air Start Airspeed
- Eliminate Ground Trim

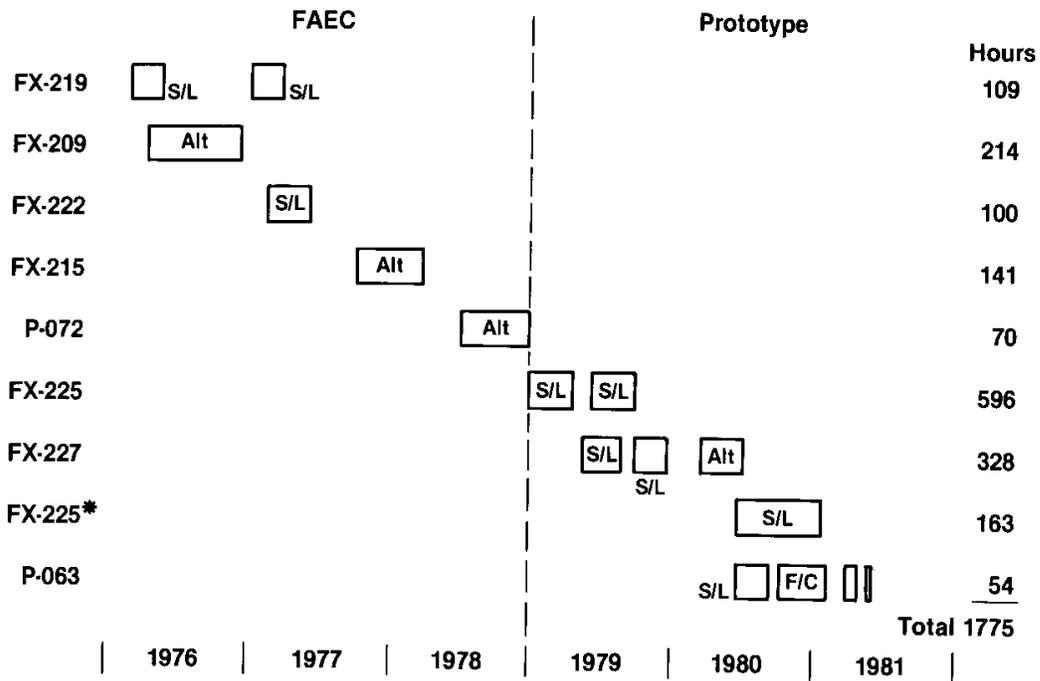
(April 1979)

SYSTEM TEST EXPERIENCE

The DEEC software, control logic, and hardware were extensively tested on a variety of F100 engines, both at sea level and in altitude facilities. Prior to 1979, the software and logic were tested using breadboard hardware which had been developed in the full authority electronic control (FAEC) program. In 1979 and later, the flight prototype hardware was also tested. Because of various failures of ground test engines in 1979 and 1980, which were unrelated to the DEEC, the flight test engine P063 was ultimately tested at sea level and in the Arnold Engineering Development Center (AEDC) altitude facility to qualify the DEEC system for flight.

DEEC System Test Experience

NASA
DFRF83-636



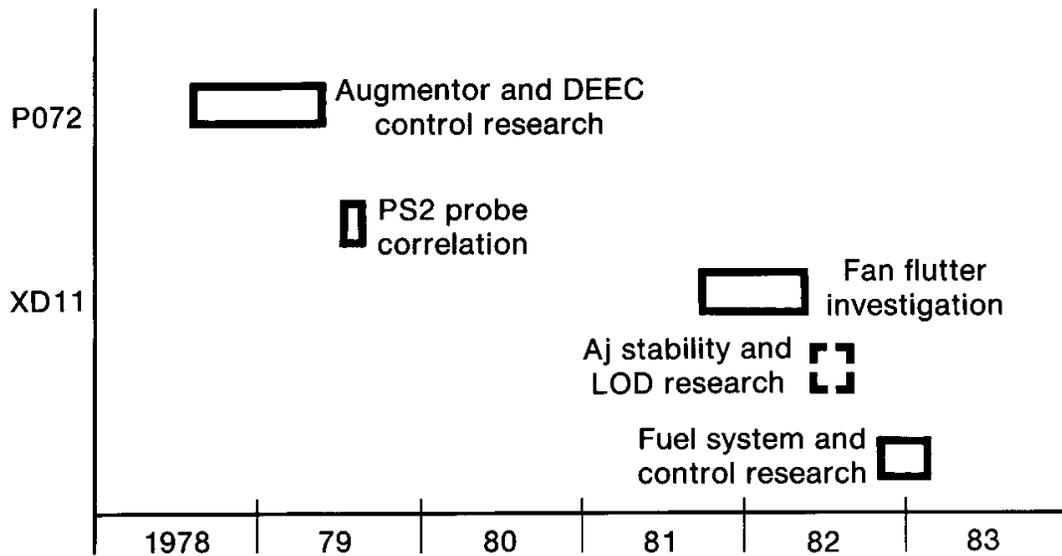
*PW 1130 Configuration

(1981)

SUPPORT FOR PW 1128 PROGRAM

The LeRC altitude facilities and engineering expertise were extensively applied to the development of the DEEC/swirl augmentor system in 1978 and 1979. The basic calibration of the fan inlet static pressure (PS2), used by the DEEC for engine control, was established at LeRC. LeRC facilities and personnel were again used in 1982 to investigate a nozzle instability observed in flight and to assist in the development of a solution to the instability. Research and development on the light off detector (LOD) used by the DEEC was also conducted at LeRC.

NASA LEWIS SUPPORT FOR PW1128 PROGRAM



AV261031 831404 3631B

P072 ENGINE TESTING

Engine testing was completed at LeRC with DEEC and a swirl augmentor (SA). Preliminary results indicated the projected improvements in operability and performance were realized.

P072 at NASA Lewis with DEEC and SWIRL A/B

NASA
DFRFB3-626a

- **Successful demonstration in ULHC and supersonic with no trim or adjustments**
- **Improved rumble tolerance (+ 7000 ft)**
- **Successful idle-to-maximum transients at Mach 0.6 and 52,000 ft**
- **PT2/PS2 correlation test with distortion scheduled**

(April 1979)

EARLY TEST RESULTS

The early results of the AEDC altitude tests in late 1979 and early 1980 seemed to confirm the benefits of the DEEC swirl augmentor observed in the LeRC test. Throttle transients, performance, airstarts, and transfers to the backup control (BUC) were demonstrated and evaluated throughout the flight envelope.

F100 EMDP Accomplishments at AEDC

NASA
DFR F83-630a

FX-227 with DEEC/SA has demonstrated successful operation throughout flight envelope

- **ULHC idle-to-maximum transients at Mach 0.8 and 47,500 ft/0.040 F/A**
- **Spooldown restarts to 200 knots at 30,000 ft**
- **Steady-state performance and transients to Mach 2.3 and 50,000 ft**
- **BUC transfers throughout flight envelope to Mach 2.3 and 50,000 ft**
- **No trim demonstrated in 82 hours**

ANALYSIS OF RESULTS

Additional analysis of the LeRC and AEDC altitude facility results indicated that the benefits observed were entirely due to the DEEC system, and not to the swirl augmentor. In fact, it was determined the swirl augmentor reduced the rumble-free altitude limits. This points out the danger of testing multiple system changes that interact with each other and where the benefits and losses due to each system are not easily separable.

P063 Augmentor Will be Non-Swirl Swirl Augmentor Has Less Rumble Margin

NASA
DFRF83-628a

Facts

- **P072 swirl augmentor test data show lower rumble-free altitude limits.**
- **FX-227 swirl augmentor shows low rumble capability.**
- **Analytical assessment predicts 1300 ft altitude loss.
Test data shows 5000 ft loss.**

Conclusion

- **Non-swirl augmentation appears more stable.**

(August 1980)

P063 AUGMENTOR FEATURES

The augmentor features selected for incorporation into the flight test engine, P063, and DEEC system are shown below. Also shown are the benefits that were expected to be produced by each feature.

NASA
DFRF83-629a

P063 Augmentor Features Augmentor Improvements Quantified and Added to P063 Flight Clearance Configuration

P063 Flight Clearance

- Ducted flameholder
- Improved cooling zero aspiration liner
- Dual ignition
- LOD

Additional Derivative II Features

- Segment VI
- Cut-back nozzle cooling liners
- Retailored S/R's

- CIP durability fixes

- Increase rumble-free altitude by 6000 ft
- Double liner life
- Reduce mislights by a factor of 3
- Stall avoidance, faster accelerations

- Increase supersonic thrust by 2 to 4%
- Increase non-augmented thrust by 1/2 %
- Increase combustion efficiency 5%
- Reduce hot streaks by 200° F
- Increase rumble-free altitude by 6000 ft
- Improved durability and reliability

(August 1980)

PO63 TEST PLAN

The major areas of test emphasis for the flight clearance of the flight test engine, PO63, and DEEC system are shown below. Items VII and VIII were not accomplished because test time ran short and they were not critical for first flight. A new back up control (BUC) schedule was to have been implemented electronically to validate its operation. The mechanical schedules implemented in the prototype BUC hardware had already been identified as needing improvement.

P063 AEDC Test Plan

NASA
DFRF83-631

- I. Instrumentation and installation checkout
- II. Sea level performance and mini-checkout
- III. ULHC A/B evaluation
- IV/V. Failure detection and accommodation
- VI. Stall recovery and avoidance
- VII. Electronic BUC evaluation
- VIII. Preliminary LOD evaluation
- IX. ULHC A/B evaluation with improvements
- X. Final flight checkout

ALTITUDE TEST RESULTS

The final flight clearance test of the flight test engine, P063, at AEDC are shown below. All major objectives were met successfully and the engine with the DEEC was declared ready for flight.

AEDC Altitude Test Results

NASA
DFR83-653a

- **BUC transfers successful**
- **Steady state performance within bands**
- **Transients OK to Mach 0.8 and 45,000 ft**
- **Airstarts successful at 200 knots/30,000 ft**
- **Bode capacity demonstrated to Mach 0.8 and 45,000 ft**
- **Stall recovery demonstrated**
- **Failure detection and accomodation validated**

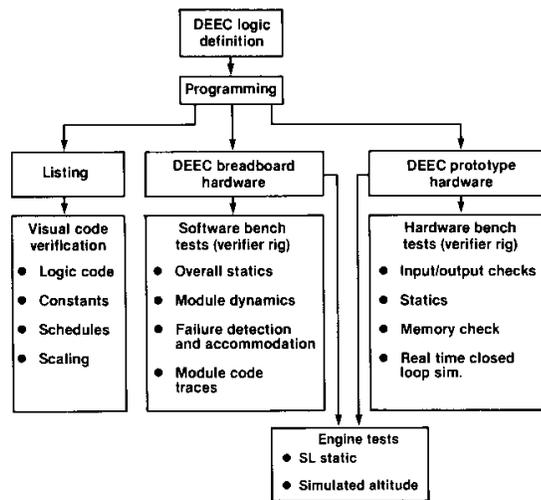
SOFTWARE VERIFICATION TEST

The DEEC software verification and validation used by Pratt and Whitney is shown below. The original process did not include the real-time dynamic closed-loop simulation. During the DEEC system review process, Dryden assigned an engineer with substantial experience in qualifying digital flight control systems for flight. The real-time simulation was added to the verification test process at his request. The simulation subsequently proved its value by identifying a previously undetected fault in the software.

DEEC Software Verification Tests

NASA
DFRF83-635

- Verification achieved through established/organized multi-level disciplines



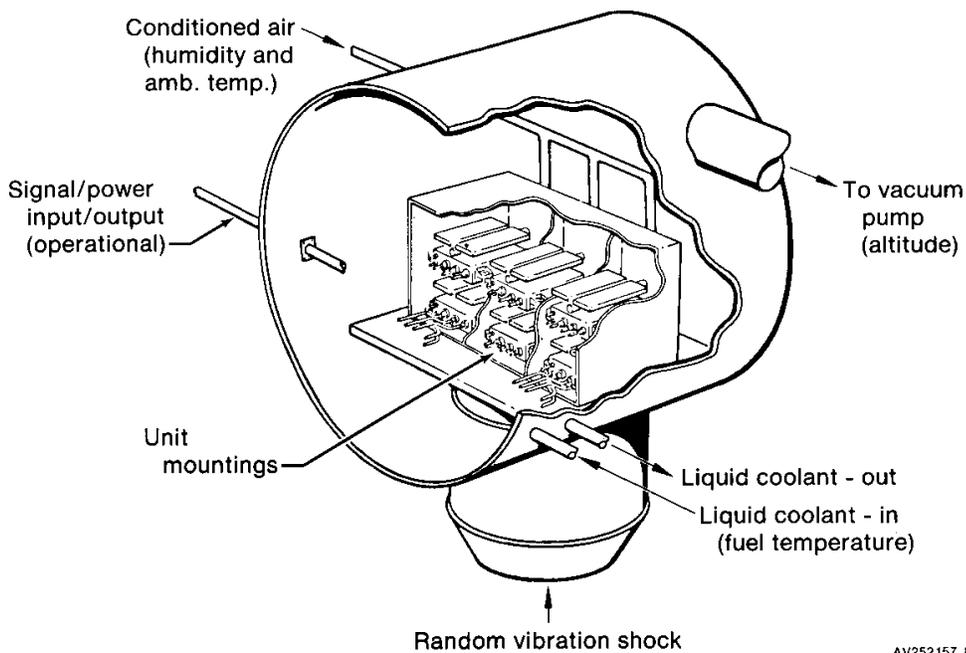
- Visual code verification, software and bench tests of 2.3.4 baseline logic completed 1980.
- Software verification review held for USAF and NASA 10/28-29/80.
- Updates incorporated in flight DEEC 2.3.6A logic.

COMBINED ENVIRONMENTAL RELIABILITY TEST

The DEEC computers underwent an extensive combined environmental and reliability test (CERT) in the laboratory as illustrated below. Six units were mounted in a chamber that was evacuated to simulate altitude. The chamber and computers were subjected to random vibrations and the air inside the chamber was conditioned to be similar to the engine bay environment. The computers were powered and running representative software programs, and were cooled with fuel. Fifty thousand hours of simulated field usage was completed on six units.

DEEC "COMBINED ENVIRONMENTAL RELIABILITY TEST" (CERT)

50,000 hours simulated field usage on 6 units, completed



AV252157 821910 0576B

MEAN TIME BETWEEN FAILURE TRACKING

The mean time between failures (MTBF) for the DEEC computer, established during the CERT, is shown below. The cumulative MTBF exceeded 1390 hours after 50,000 hours of simulated field usage. Components that were found to have marginal or inadequate performance in the CERT were replaced in the flight DEEC units as they were identified.

DEEC CERT TEST MTBF TRACKING

